



## DELIVERABLE D 1.2



# The North Sea-3S\* case Study

\* 3S for Seine, Somme, Scheldt watersheds

How to achieve sustainable water ecosystems management connecting research, people and policy makers in Europe (AWARE)

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RE Restricted to a group specified by the consortium (including the Commission Services)

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# **AWARE Programme**

**Inception report**

**December 2009**

## **North Sea Case study and 3S watersheds**

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# **North Sea Case study**

- 1. DESCRIPTION OF THE SYSTEM AND ITS FUNCTIONNING**
  - 1.1. Introduction to the system**
  - 1.2. The marine system and the eutrophication issue**
    - 1.2.1. Nutrient balance and the eutrophication process
    - 1.2.2. Past trends in nutrient river inputs and eutrophication
  - 1.3. River water quality and drinking water resources**
  - 1.4. Economic and social description of the system**
  - 1.5. The Governance framework of the system**
    - 1.5.1. Policy makers
    - 1.5.2. Stakeholders
- 2. THE POLICY ISSUE**
  - 2.1. How have we got there?**
    - 2.1.1. Wastewater treatment
    - 2.1.2. Agriculture
  - 2.2. Current issues and initiatives**
- 3. SCENARIOS BUILDING and EVALUATION: the science-policy interface**
  - 3.1. Scenarios building**
  - 3.2. Available models to evaluate scenarios**
    - 3.2.1. Description of the models
    - 3.2.2. Examples of scenarios
- 4. KEY SCIENCE POLICY QUESTIONS.**
- 5. LITERATURE**

# 1. DESCRIPTION OF THE SYSTEM AND ITS FUNCTIONNING

## 1.1. Introduction to the system

The issue of concern in the North Sea Case study is the eutrophication of the coastal zone of the eastern Channel and Southern North Sea (FCZ and BCZ), where harmful algal blooms (HABs) are occurring every spring. The particular circulation of the marine water masses is such that nutrient delivered by the Seine, the Somme and the Scheldt (the 3S) rivers cumulate along a SW-NE direction (Fig. 1). The agricultural, domestic and industrial activities all over the hydrological basin of these three rivers (i.e. the area they drain) result in very high nutrient loading, particularly in terms of nitrogen and phosphorus. The system under study, i.e. the territory where management measures can be taken, thus includes an area of as much as 100 000 km<sup>2</sup> in France and Belgium. Over this large territory, many other water issues are at stake, which also should be considered by water management policies. The Case Study thus concerns the whole aquatic continuum from headwaters in the Seine, Somme and Scheldt watersheds, their groundwater resources, the large rivers and their estuaries and finally the coastal zones of the North of France and Belgium. Coastal eutrophication and the resulting harmful algal blooms (mucilaginous –*Phaeocystis*- and/or toxic –*Dinophysis*- algae) must be considered not only for themselves but also as the telltale sign of a disturbed functioning of the upstream territory.

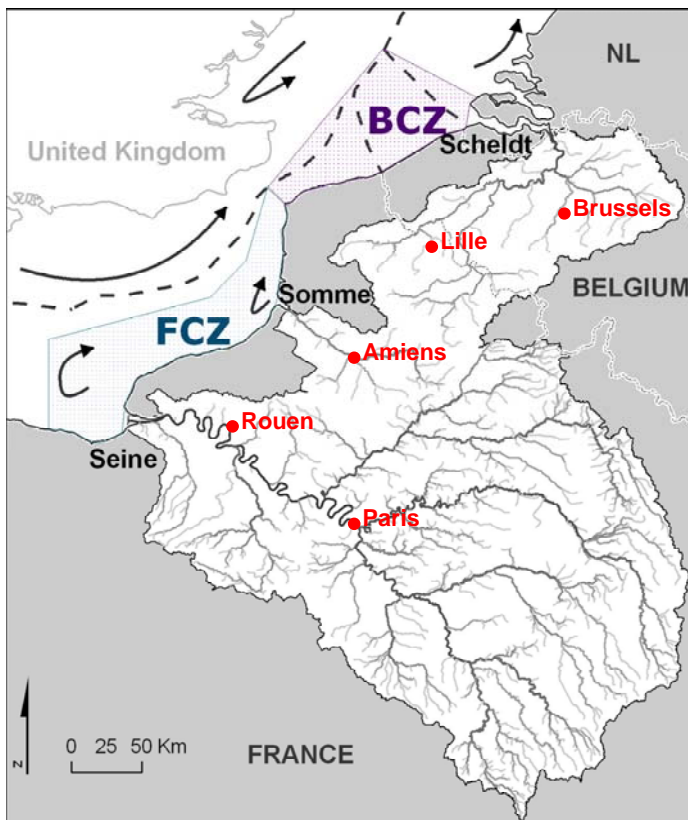


Figure 1. French (FCZ) and Belgian (BCZ) Economic Exclusive Zones (dotted line) and the contributing watersheds.

## 1.2. The marine system and the eutrophication issue

### 1.2.1. Nutrient balance and the eutrophication process

Rivers deliver to the coastal sea essential biogenic elements like nitrogen (N), phosphorus (P) and silicon (Si) for phytoplankton growth. North Sea coastal eutrophication is the consequence of the increased river inputs of N and/or P originating from human activity in the watersheds, while silicon is little affected. Both the amount of nutrients delivered by rivers and their respective ratios determine the response of coastal ecosystems. All phytoplankton species require both N and P to grow, while only diatoms, the ‘preferred’ algae which serve as food for zooplankton and fish require Si. As long as N and P are brought by rivers in balance with Si, diatoms blooms occur in the sea, with beneficial effects for the trophic chain. When N and P are in excess over Si with respect to the requirements of diatoms, then non siliceous algae dominate, which are less efficiently grazed and form undesirable blooms often associated with harmful effects, like foam accumulation (Fig. 2).



*Figure 2: Foam accumulation on the beach resulting from accumulation of non-siliceous phytoplankton-derived organic matter (Ostend, May 1998)*

An indicator, the ICEP (for indicator of coastal eutrophication potential; Billen and Garnier, 2007) represents this imbalance between nutrients delivered by the rivers. It is defined as the production of non siliceous algal biomass potentially sustained in the receiving coastal water body by N or P brought in excess over Si. Negative value of the ICEP indicates the absence of eutrophication problems, while positive values indicate an excess of either N or P over the requirements for diatom growth, thus a condition for a potential development of harmful non siliceous algal. With P being the limiting nutrients

for the 3S rivers, ICEP values vary from 4 to 6 kgC/km<sup>2</sup>/d for the Seine and the Scheldt for wet and dry years respectively, e.g. systematically above zero, but fluctuate around zero for the Somme depending of the hydrology (-0.2 kgC/km<sup>2</sup>/d for wet to 1.2 kgC/km<sup>2</sup>/d for dry years).

In the case of the Belgian coastal waters, *Phaeocystis* is the non siliceous algae involved. This flagellate, when present at densities higher than about 4 10<sup>6</sup> cells L<sup>-1</sup>, forms large mucilaginous colonies, which cannot be grazed by zooplankton, thus severely reducing the capacity of the marine ecosystem to efficiently transfer its primary production to higher trophic levels. This decrease in trophic efficiency is related to an imbalance between N and P inputs, which should be maintained in a ratio (molar N:P) lower than 25, for allowing dominance of diatoms over *Phaeocystis* blooms (Lancelot et al. 2009).

### 1.2.2. Past trends in nutrient river inputs and eutrophication

The nutrient delivery by the Seine and the Scheldt is well monitored since about 30 years (Fig. 3) and could be recalculated by model simulations for earlier periods (Fig. 4). For P and N, present-day fluxes are ten to fifty times higher than the pristine levels. The recent data show (i) a regular increase of N fluxes, also influenced by the pluri-annual cycle of water discharge variations; (ii) a large increase in P delivery until the late 1980's followed by a rapid decrease during the last 2 decades; (iii) no clear trend, beyond that of water discharges variations for silica. These trends reflect the changes which occurred in human activity in the watersheds, and will be discussed below.

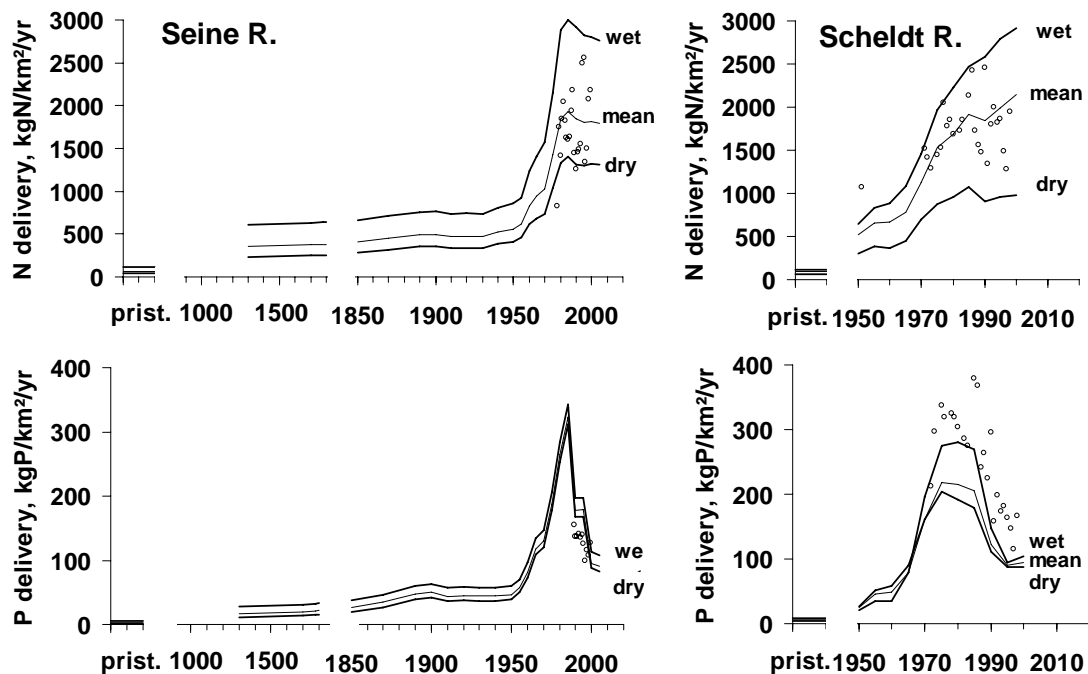


Fig. 4. Model reconstitution of long term changes in nutrient fluxes by the Seine and Scheldt rivers, for 3 hydrological regimes (dry, wet and mean).

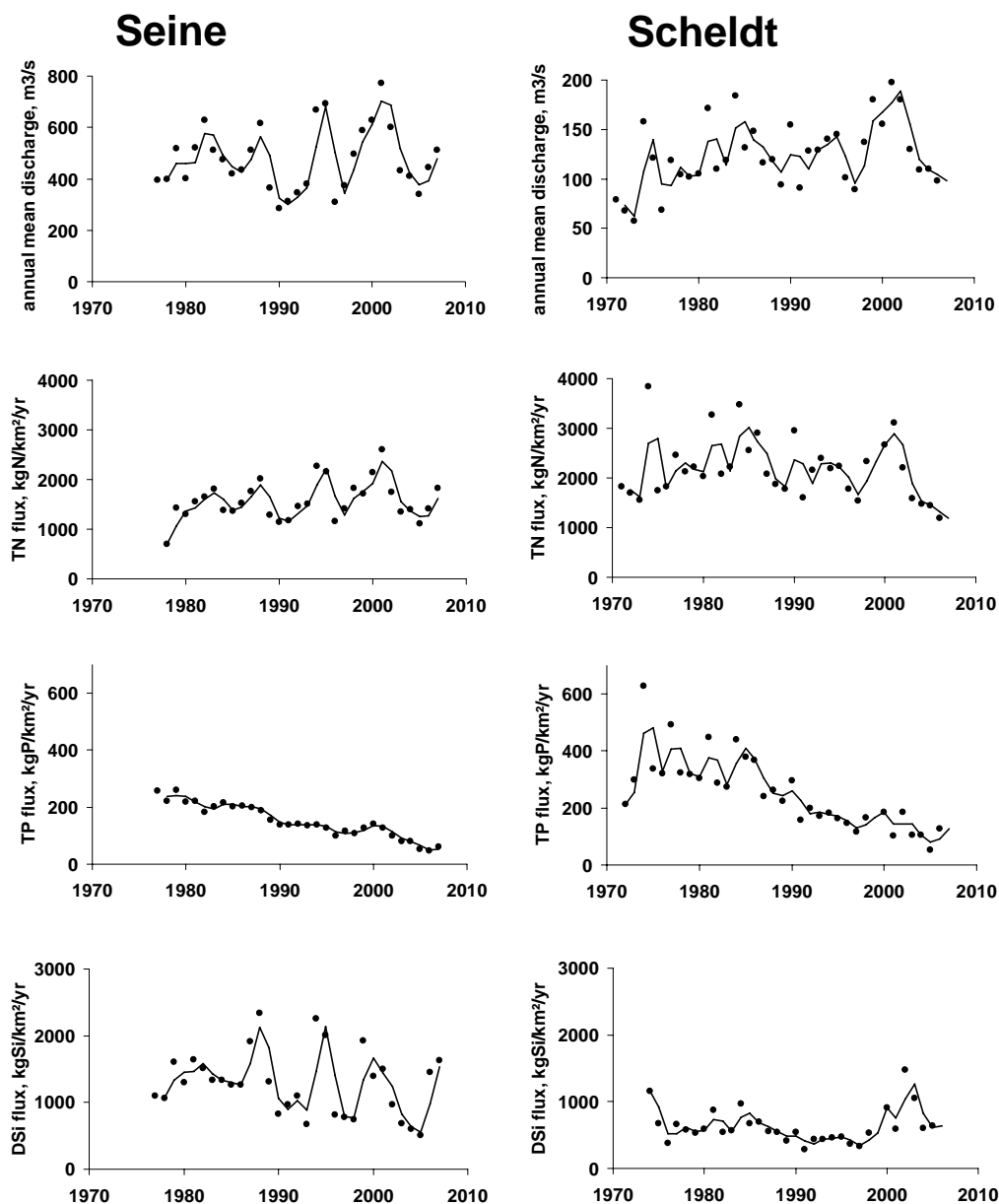


Fig. 3. Observed trends in nutrient loading delivered by the Seine and Scheldt rivers to the sea since 1970

Long term model simulations aiming at reconstructing the past situation of *Phaeocystis* colony blooms in the Southern North Sea has shown that large colonies were not present under pristine conditions. Field observations reported their presence at the turn of the 19th century, but bloom events have increased in duration and intensity from the years 1950's on (Cadée and Hegeman, 1991; Lancelot et al., 2007).

Since 40 years, the maximum level of *Phaeocystis* blooms reached in the Belgian coastal zone has increased (Fig. 5). The current trend is either to a slow increase or a levelling off. No sign of recovery is observed in spite of the marked decrease of phosphorus delivery. Clearly, the still high nitrogen inputs play a pivotal role.



By contrast, in the Seine river plume, off the Calvados coasts, the occurrence of toxic *Dinophysis* algal blooms seems to gradually decrease since a dozen of years (Fig. 6) but could still reach the cell threshold for toxicity i.e., 10 000 cell L<sup>-1</sup>.

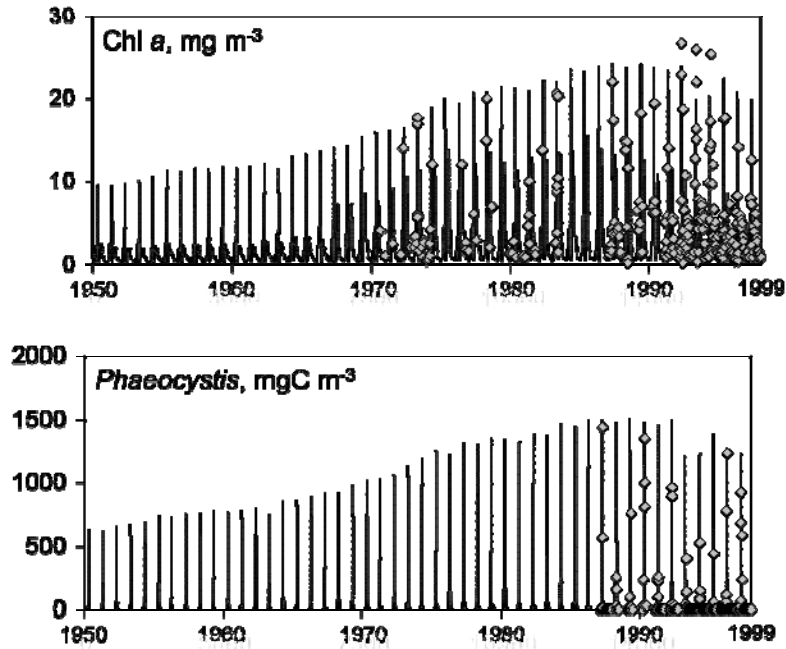


Fig. 5: Time series of chlorophyll *a* (Chl *a*) concentrations and *Phaeocystis* biomass in the BCZ

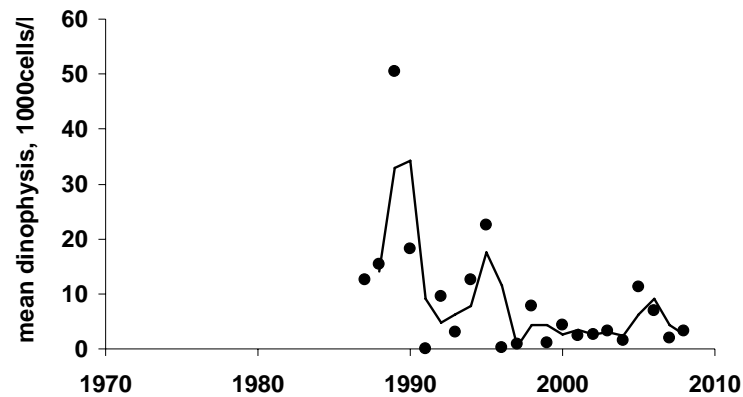


Fig. 6. Trends in the mean *Dinophysis* (toxic non siliceous algae) cell numbers off Antifer in the Seine river plume.

### 1.3. River water quality and drinking water resources

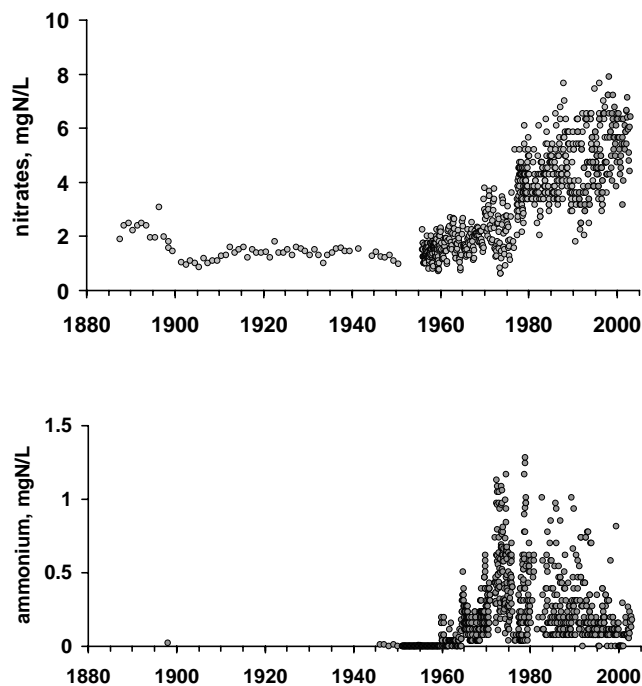
While coastal eutrophication is an obvious environmental problem in itself, causing damage to local economic activities (see below), the increase of nutrient (N and P)

contamination of river and groundwater water quality in the watersheds is also a serious environmental thread.

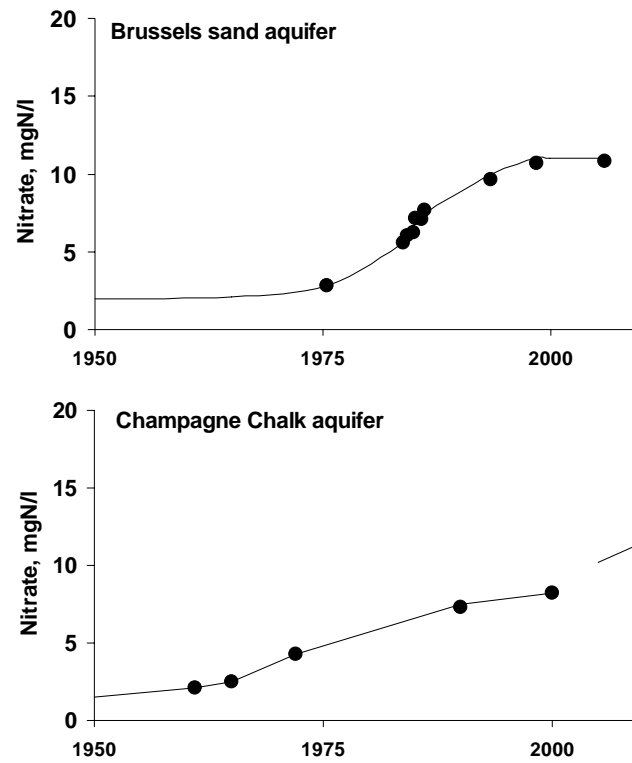
Nutrients are transferred from the watershed to surface water along two distinct pathways. Diffuse contamination occurs through soil leaching and erosion, thus reflecting the intensity of the use of fertilizer in agriculture. Point contamination results from the direct discharge of urban wastewater into surface water.

Algal blooms in large rivers may still cause severe problems of water quality and difficulties in drinking water production. Nitrate contamination, which concerns both surface and groundwater resources, is becoming alarming because it often approaches the drinking water standard of  $50 \text{ mgNO}_3/\text{l}$  ( $=11 \text{ mgN/l}$ ).

Fig. 7 shows the nitrate and ammonium concentrations of the Seine River water upstream from Paris (thus reflecting the contribution of the rural territories upstream in the basin). Fig. 8 summarizes the trend of nitrate contamination in a number of major aquifers in the Seine and Scheldt watersheds.



*Fig. 7. Long term variation of nitrate and ammonium concentration in the Seine river upstream from Paris (Ivry water intake).*



*Fig. 8. Long term trends in nitrate contamination of the Brussels sands aquifer (Scheldt basin) and of the Champagne Chalk aquifer (Seine basin).*

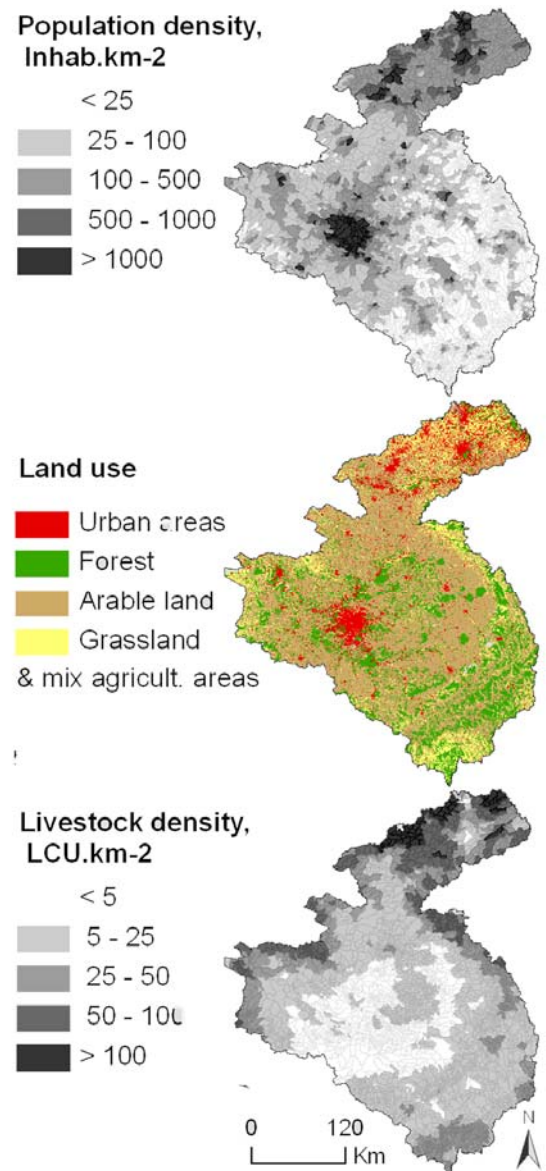
## 1.4. Economic and social description of the system

The basins of the Seine, Somme and Scheldt rivers extend over one of the area in the world with most important population densities, industrialization and intensive agriculture.

The population of the Seine basin (mean 213 inhab/km<sup>2</sup>), is dominated by the huge Paris agglomeration (10 millions inhabitants), while the density is very low in the upstream regions of the basin (Fig. 9a). The Somme basin has a more uniformly distributed population (mean 99 inhab/km<sup>2</sup>). The Scheldt basin has the highest population density (mean 497 inhab.km<sup>-2</sup>).

Land use is dominated by arable land in most of the Seine and Somme basins, excepted the eastern and western fringes of the former, while urban areas, as well as grassland and mixed agricultural areas dominates in the Scheldt basin (Fig. 9b).

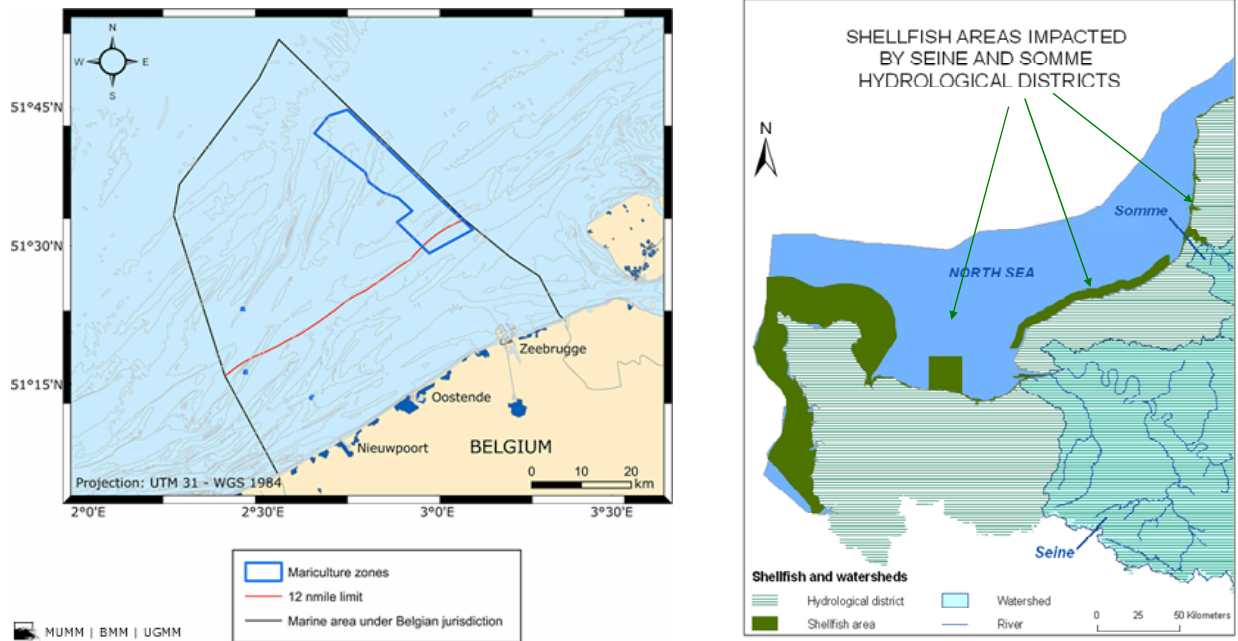
These differences are in accordance with the orientation of agriculture toward cereals and industrial crop production in the Seine and Somme basins, and toward livestock farming (including intensive pig and poultry production) in the northern part of the Scheldt basin. The distribution of livestock density, expressed in LU (Livestock Unit = 1 milking cow, or 10 fattening pigs, or 143 laying hens, 333 battery chickens,...) displays the same features, with a mean of 15, 23,70 LU/km<sup>-2</sup> for the Seine, Somme and Scheldt basins respectively (Fig. 9c).



*Fig. 9. From top to bottom: a) Population of the Seine, Somme Scheldt basins, b) land use and c) distribution of the livestock.*

Economic activity in the coastal zones includes industrial activity, tourism, fishing and shellfish farming (inshore in the FCZ and offshore in the BCZ, Fig. 10a). As an example, the Belgian coast is a great tourist attraction for both Belgian and foreign visitors. About 30 million people visit this coast every year, of which about 17 million stay overnight.

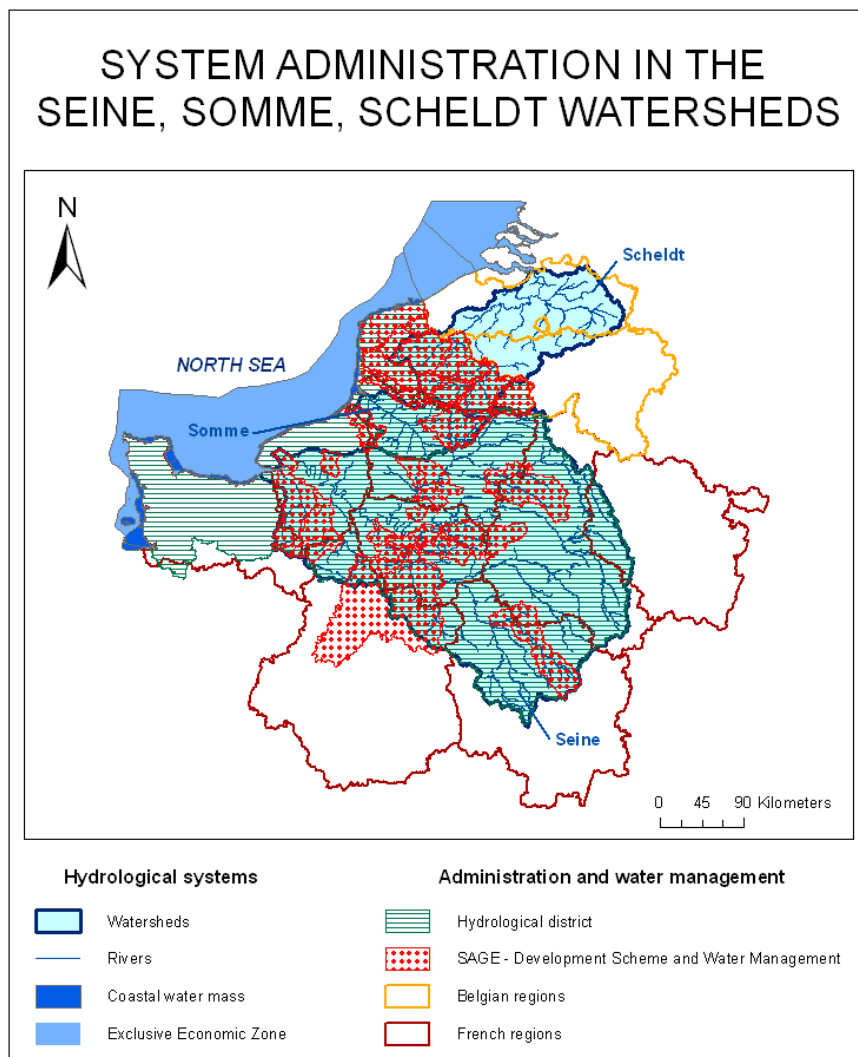
In addition maritime transport is very intensive with subsequent risk for marine ecosystems. Similarly the Seine and the Somme deliveries have impacts on the large shellfish areas (Fig. 10b)



*Fig.10: Location of the mariculture zones in the Belgian EEZ (left) and the shellfish areas of Southern North Sea impacted by the Somme and Seine (right).*

## 1.5. The Governance framework of the system

The area considered is characterized by a complex superposition of administrative and management authorities (Fig. 11), as it spreads over 2 countries and 9 administrative regions.



*Fig. 11. Limits of the administrative and management authorities in the Seine, Somme and Scheldt and associated coastal EEZ*

#### 1.5.1. Policy makers

The EU Water Framework Directive (EU WFD), the leading governance frame, organizes the management of water resources by Hydrological Districts, corresponding to the large watersheds.

As far as the Seine basin is concerned, the Seine-Normandie Water Agency is in charge of the implementation of all decisions pertaining to water management. It acts as the executive organism of the Basin Committee, composed of representatives of the French State, Regions and local communities as well as of members of the civil society. The Basin Committee has developed, in line with the prescription of the EU WFD, a general Development Scheme for Water Management (SDAGE) as well as more local measure programs (SAGE), in order to achieve the objective of a ‘Good Ecological Status’ of all water masses by 2015.

Similarly, the Artois-Picardie Water Agency is responsible for the Somme basin. It is also involved, with the Walloon, Flemish and Brussels Region, in the management of the

International Scheldt Water District, in the scope of the International Scheldt Commission (ISC) which plays the role of Basin Committee for this transboundary watershed.

Water Agencies can act neither as project manager nor as project owner for the works to be carried out in the frame of water management, as e.g. wastewater purification plants. A lot of organisms, either local communities or syndicates, are in charge of this, at the local scale. For instance, the SIAAP (Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne) is responsible for Paris wastewater treatment. For Brussels, this is the IBGE (Institut Bruxellois pour la Gestion de l'Environnement), in Flanders, the VMM (Vlaams Milieumaatschappij) and in Wallonia, the SPGE (Société Publique de Gestion de l'Eau).

The management of marine waters is also organized at the international level through the Commission established by the Convention for the Protection of the Nord-East Atlantic (Oslo-Paris, OSPAR Convention) as well as by the EU Directive on Marine Strategy (2008/56/EC), which requests a good ecological status of marine waters in 2020.

In Belgium the Federal State (Federal Public Service Health - Directorate General Environment - Marine Environment Service is responsible for coastal water quality in the economic exclusive zone.

### **1.5.2. Stakeholders**

As stated above, all human activities related to food production and consumption in the territory of the Seine, Somme and Scheldt watersheds has an impact on fresh and marine ecosystem. Enumerating and mapping all the stakeholders involved in this matter is for us an unfeasible task. We here limit ourselves to provide an overall framework (Fig. 12).

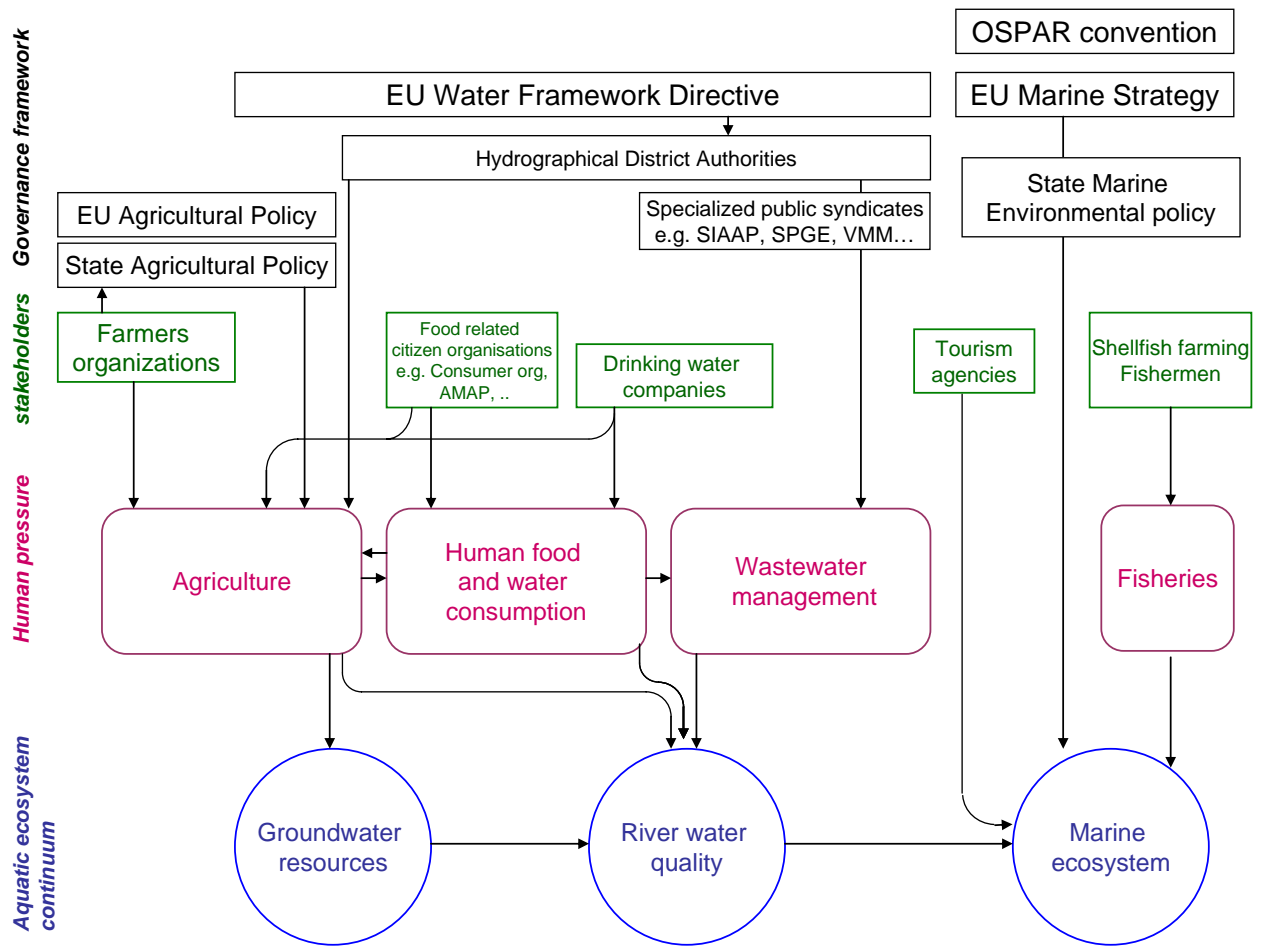


Fig. 12. A schematic view of the different interactions between the aquatic system, the human food system, the governance framework and the actors in the studied watersheds.



## 2. THE POLICY ISSUE

As said above, North Sea coastal eutrophication is the consequence of the riverine inputs to the coastal zone of biogenic elements like nitrogen (N), phosphorus (P) issued from agricultural and urban areas in the watersheds and that add to 'natural silica fluxes (Si)'. It therefore closely depends on how people live in the basin, more specifically how they produce their food and how they manage the wastewater produced by its consumption: coastal eutrophication is a part of the environmental imprint of the human food system ("the food-print").

First, we will here present a short summary of the policies which have conducted during the last decades to the situation described above. Then we will try to analyse what is at stake in a number of current debates and initiatives.

### 2.1. How have we got there?

#### 2.1.1. Wastewater treatment

Urbanization, and domestic drinking water distribution, lead to an extreme concentration of wastewater production. The model of the 'tout à l'égout', generalized at the end of the 19th century in the largest cities of Western Europe and then extended to the smallest ones during the 1950's, first resulted in a severe contamination of surface water in organic matter and nutrients.

Wastewater treatment plants were gradually implemented to all sewer outlets. However, basic wastewater treatment (as e.g. by the activated sludge process) just eliminate organic matter by mineralization, thus avoiding oxygen deficits in the receiving water bodies; it does not greatly affect the nitrogen and phosphorus load of wastewater, which represents 10-15 gN/inhabitant/day and 1.0 gP.inhab<sup>-1</sup>.day<sup>-1</sup>. From the years 1960 on, the per capita P loading even increased to 4 gP.day<sup>-1</sup> due to the introduction on the market of washing powders containing phosphate, before decreasing again down to 1.5 gP.day<sup>-1</sup> in recent years owing to the ban on P in detergents.

Specific treatments to remove N and P were only recently implemented on the largest wastewater treatment plants. In 1991, the EU Directive on Urban Wastewater Treatment (91/271/EEC) rendered compulsory the reduction of N and/or P in all WWTP larger than 10000 equivalent inhabitants in sensitive areas (i.e. those concerned by eutrophication problems). In many places, the application of this directive has been much delayed, but the implementation of tertiary treatment of P and N is now being decided. Regarding the largest WWTP of the Paris conurbation in the Seine basin, changes has been observed from the year 2008, especially concerning the discharge of phosphorus and ammonium, which was nitrified along the 200 km to the estuary causing oxygen depletion far from the discharge point. Nitrogen should be entirely treated by the years 2012. Also, in Brussels, where no treatment of effluents occurred at all before 2000, two efficient ones now treat P and N since 2007.

### 2.1.2. Agriculture

Since the late 1950's the European Common Agricultural Policy has strongly encouraged the transition from traditional agriculture, based on the balance between crop farming and animal husbandry, toward the current industrial agricultural system. The first objective was to reach European food self-sufficiency, by guaranteeing prices, by increasing agricultural productivity, encouraging concentration and regional specialisation. Thus, the Seine and the Somme basins specialized themselves toward cereal production based on synthetic fertilization, while the Scheldt basin shifted to intensive animal farming largely based on feed importation (Fig. 13).

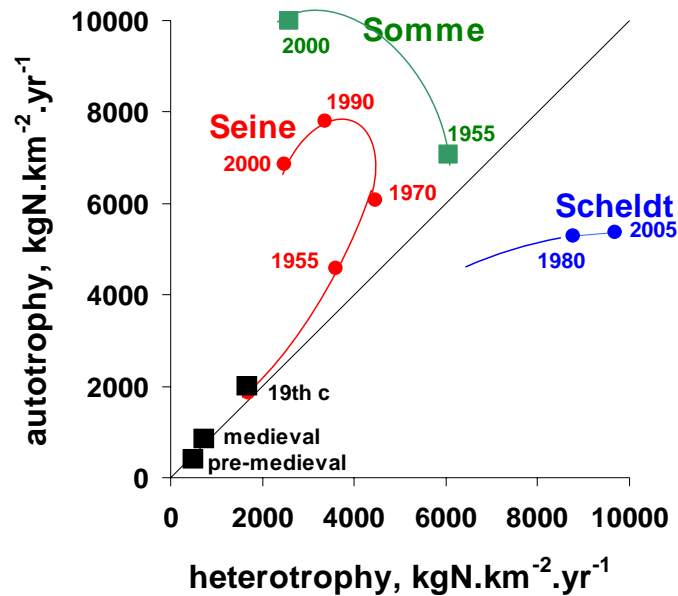


Fig. 13. Trajectory of the Seine, Somme and Scheldt basins in terms of autotrophy (total agricultural production expressed in terms of nitrogen content) and heterotrophy (total local consumption by human and domestic animals).

The disappearance of organic fertilization in favour of synthetic fertilizers in areas specialized in crop production, and conversely the structural manure excesses in areas livestock farming areas resulted in the deterioration of agricultural soil and an increase of diffuse sources of nutrients to surface and groundwaters.

Adoption of modern farming practices were encouraged through the establishment of a dense network of agricultural advisors, first issued from the Chambres d'Agriculture (public organisations elected by the farmers at the regional scale), but more and more competed by representatives of commercial firms or cooperatives. Large operations of landscape modifications like regrouping of lands or wetland drainage were carried out with the aid of the State, and credits were made easily available for mechanisation. All this resulted in a kind of technical locking of the farming systems, where farmers were more and more deprived of their autonomy.

This policy led to a major overproduction crisis as soon as the 1980's, for which measures were taken by the EC to limit production by establishing milk quota (1984) and setting-aside a fraction of arable land (1992).

The threat this modern agricultural system represents for the environment was only taken into account in the Common Agricultural Policy with its reform of 1999, oriented towards a more multi-functional agriculture and agro-environmental measures. In parallel, the Nitrate Directive, adopted in 1991, aimed at reducing nitrate inputs in ground- and surface water due to farming activities. The first step was to map 'vulnerable zones', i.e. areas where eutrophication is important or where the nitrate concentration in drinking water resources is over 50 mgNO<sub>3</sub>/l. In those areas the most polluting farming practices should be avoided or modified in order to improve water quality. By 2004 – 2007, an assessment at local and national scales of the implementation of the directive should have been carried out. France was condemned by the EU Justice Court in 2003 to have failed in the identification of many vulnerable zones, including those responsible for eutrophication of the Seine Bight (Fig. 14). This leads to identify the whole of the Seine Basin as a vulnerable zone.

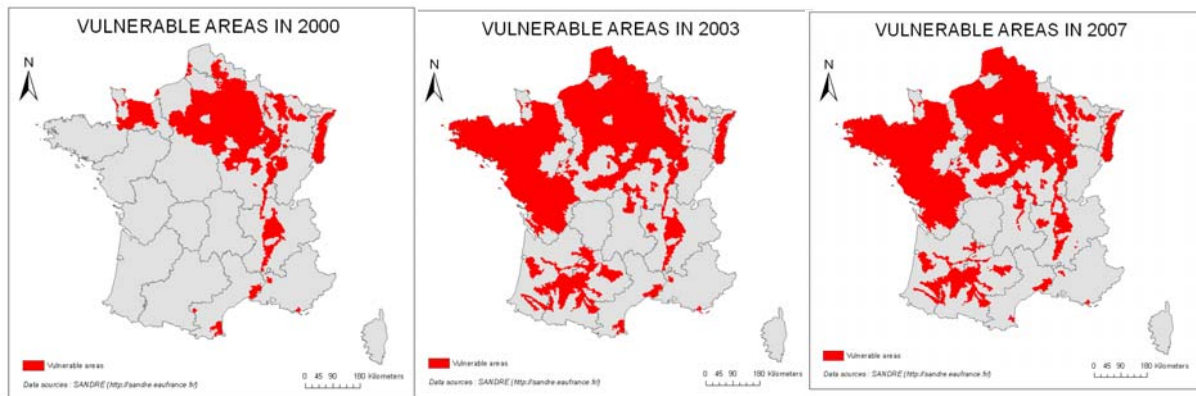


Fig. 14. Successive definition of vulnerable areas (for the EU Nitrate Directive) by the French Authorities, in 2000, 2003 and 2007 (<http://sandre.eaufrance.fr/>)

In the scope of the implementation of the Water Framework Directive (2000), and following the discussions at the Grenelle de l'Environnement (2007), the limit for 'good ecological status' in terms of nitrate concentration is still set at 50 mgNO<sub>3</sub>/l for both surface and water masses, although many voices advocate a much lower limit close to 10 mgN/l.

The measures envisaged to limit nitrogen leaching of nitrogen fertilizers in intensive agricultural areas consist of limitation of fertilizers application, systematic insertion of catch crops during long periods of bare soils in crop successions, establishment of uncultivated buffer strips around rivers. Experimental and modelling work shows that such measures are only able to reduce nitrogen leaching by 30% at most.

## **2.2. Current issues and initiatives**

Owing to the efforts devoted to urban wastewater treatment by local and governmental authorities, the point sources of nutrient to surface water are now about to be under control. The EU WFD imposes very clear obligations in that matter, and the necessary investments have been decided. As a consequence, phosphorus loading, which mostly depends on point sources, is rapidly decreasing. Nitrogen on the other hand is mostly originating from diffuse agricultural sources, so that much less progress is to be expected from improvement of nitrogen removal from urban effluents, if nothing changes in the agricultural sector. Expensive technical measures to further reduce nitrogen in wastewater treatment plant can legitimately be questioned.

Nitrogen pollution from industrial agriculture remains the main issue, both in terms of alteration of drinking water resources and of marine eutrophication problems.

Governmental authorities struggle for imposing agro-environmental measures which are not easily accepted by farmers and have only limited effectiveness. In the same time a large number of non governmental organizations, as well as individuals, recommend a radical change in our food production system. These include defenders of organic farming and of local food supply, promoters of a human diet containing less meat and animal products, as well as citizens groups trying to re-establish links between the city and its surrounding countryside. The objectives of these groups often join up with those of drinking water authorities concerned with the alteration of their local water resources.

### **3. SCENARIOS BUILDING & EVALUATION: science-policy interface**

The policy question at stake in the AWARE project is to link the way we want to organize society (more specifically our food system, including agriculture, human diet, drinking water production and wastewater management) to the health of aquatic ecosystems, from rivers to coastal zones.

In practice, starting from a description of the present situation, this would involve the building up of scenarios of measure implementation or changing human pressures, and predicting the changes brought by these scenarios to the quality and functioning of the aquatic environments. While creative imagination is the most important quality required for building scenarios, predicting its effect requires suitable operational models.

#### **3.1. Scenarios building**

Scenarios building can involve changes in agricultural practices, in human diet, in wastewater treatment. They can be limited to simple measures to be implemented to some sector of activities, or involve radical changes in the way people live (and eat) in the watersheds. They can incorporate changes brought in the landscape and waterscape of the territory. An example would be the systematic impoundments of small ponds as they once existed in the rural areas, and are known to represent efficient way to reduce the nitrate loading of agricultural waters.

Some rough economic valuation of the measures proposed is a useful way of testing the realism of the scenario.

#### **3.2. Models available for evaluating scenarios**

The two teams involved in the AWARE **North Sea Case study** have developed together a suite of mathematical models allowing to describe (i) the transfer of nutrients (N, P, Si) from the watershed soils through the drainage network of the Seine, the Somme and the Scheldt rivers (SENEQUE-RIVERSTRAHLER model), and (ii) the functioning of the first trophic levels of the French and Belgian coastal zones receiving the riverine fluxes (MIRO model).

The coupled models were validated for a reference year (2000), and for two other hydrological years 1996 and 2001, representing respectively a dry and a wet situation (Thieu et al., 2009; Lancelot et al., sub.). These models now offer an optimized tool to explicitly assess the impact of any change in human activity and to investigate management scenarios for recovering well balanced nutrient deliveries along the French and Belgian coastal zones. The SENEQUE-RIVERSTRAHLER model already allowed to explore several planned mitigation measures for limiting stream nutrient contamination, and when coupled with the MIRO model to analyse how/when the balanced nutrient ratios can be restored at the coastal zone for preventing eutrophication problems. The major scenarios tested relate to the objectives of the Water Framework Directive (WFD) and two major types are explored, i) those increasing the point source

treatments in waste water treatment plants (WWTP), ii) and others reducing nutrient input from agriculture.

### 3.2.1. Model description

The RIVERSTRAHLER model (Billen et al., 1994; Garnier et al., 1995; 2002; Billen and Garnier, 2000; Garnier and Billen, 2002) describes the drainage network of any river system as a combination of basins, represented as a regular scheme of confluence of tributaries of increasing stream order, each characterized by mean morphologic properties, connected to branches, represented with a higher spatial resolution. The advantage of this representation of the drainage network is that it takes into account, with reasonable calculation time, both the processes occurring in small first orders (i.e., headwater streams) and those occurring in large tributaries. The water flows in the hydrographical network are calculated from the specific discharges generated within the watershed of the different sub-basins and branches considered. Specific discharges are calculated from rainfall and potential evapotranspiration by a simple two-compartment rainfall-discharge model that distinguishes two components: surface, or sub-root (hypodermic) runoff, and groundwater, base flow (Fig. 15).

The essence of the model is to couple these water flows that are routed through the defined structure of basins and branches with a model describing biological, microbiological, and physicochemical processes that occur within the water bodies. The module representing the kinetics of the processes is known as the Rive Model. The state variables comprise nutrients, oxygen, suspended matter, dissolved and particulate non-living organic carbon, and algal, bacterial, and zooplanktonic biomasses. Most processes important in the transformation, elimination, and/or immobilization of nutrients during their transfer within the network of rivers and streams are explicitly calculated, including algal primary production, aerobic and anaerobic organic matter degradation by planktonic as well as benthic bacteria with coupled oxidant consumption and nutrient remineralization, nitrification and denitrification, and phosphate reversible adsorption onto suspended matter and subsequent sedimentation. Garnier et al. (2002) provides a detailed description of the Rive Model and of the physiological parameters used. Besides morphological and climatic constraints, the Riverstrahler takes into account diffuse and point sources of nutrients from land-based anthropogenic sources. Diffuse sources of nutrients through surface and groundwater respectively are assigned a constant concentration for all nutrients. Point sources, which are typically wastewater discharges, must be specified by stream-order for the basins and at their exact location for the branches.

MIRO is also a mechanistic biogeochemical model describing, N, P and Si cycling through aggregated components of the planktonic and benthic realms of *Phaeocystis* dominated ecosystem (Lancelot et al., 2005; Lancelot et al., 2007). Its structure includes thirty-eight state variables assembled in four modules describing the dynamics of phytoplankton (diatoms, nanoflagellates and *Phaeocystis*), zooplankton (copepods and microzooplankton), dissolved and particulate organic matter (each with two classes of biodegradability) degradation and nutrients ( $\text{NO}_3$ ,  $\text{NH}_4$ ,  $\text{PO}_4$  and  $\text{Si(OH)}_4$ ) regeneration by bacteria in the water column and the sediment. Equations and parameters were formulated based on current knowledge on the kinetics and the factors controlling the

main auto- and heterotrophic processes involved in the functioning of the coastal marine ecosystem (Fig. 14).

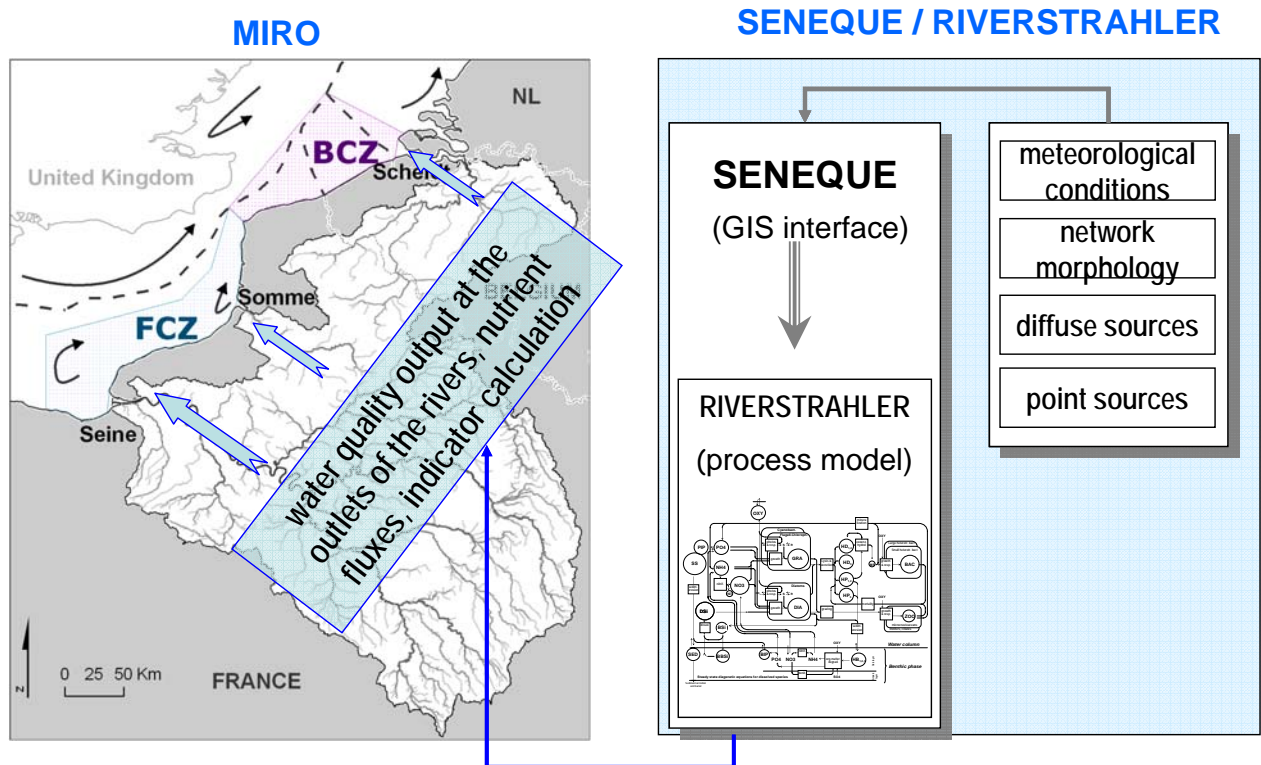


Fig. 15. Schematic representation of the coupled model of the 3S and adjacent coastal zone (MIRO and Seneque/Riverstrahler).

The MIRO model is implemented in a multi-box frame delineated on the basis of the hydrological regime and river inputs. In order to take into account the cumulated nutrient enrichment of Atlantic waters by the Seine, Somme and Scheldt rivers, successive boxes, assumed to be homogeneous, have been chosen from the Seine Bight to the BCZ. Each box has its own morphological characteristics (see Lancelot et al., 2005) and is treated as an open system, receiving waters from the upward adjacent box and exporting water to the downward box. MIRO was first calibrated for 1989–1999 climatic conditions of river loads, global solar radiation and temperature calculated from available data and its prediction capability was demonstrated by its ability to reproduce the SW–NE nutrient enrichment gradient observed from the Western Channel to the Belgian Coastal Zone as well as the mean seasonal nutrient and ecological features recorded in the central BCZ during the last decade (Lancelot et al., 2005).

### 3.2.2. Examples of results

Examples of results are shown in Fig. 16 (from Thieu et al, in press and in prep). The first scenario shown represents a business as usual scenario, showing what would occur if nothing were changes in the current agricultural and wastewater management practices. The second scenario corresponds to the short term effect of improvement of wastewater treatment according to the requirements of the WFD, and to the systematic implementation of agro-environmental measures (mainly catch crop insertion). The third scenario represents the effect of the generalization of organic agriculture over the whole agricultural territory of the 3 basins.

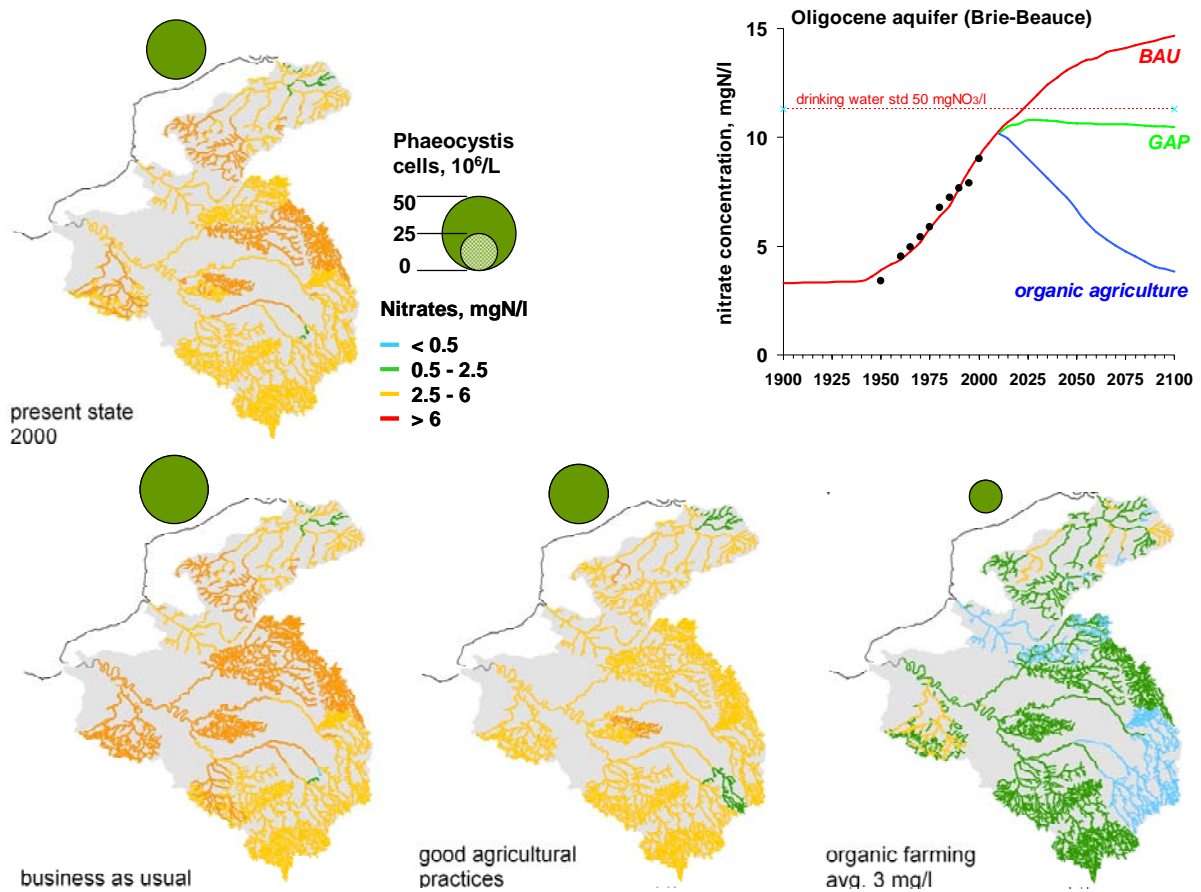


Fig 16. a. present situation of nitrate contamination of aquifers and surface water in the seine, Somme and Scheldt watersheds, and extend of Phaeocystis blooms in the Belgian coastal zone. b. Business as Usual scenario for 2050; c. Scenario corresponding to the strict application of the WFD. d. A more radical scenario involving complete conversion of agriculture to organic practices.



#### 4. KEY SCIENCE POLICY QUESTIONS.

- How define good ecological status for the coastal systems under study and which reduction of nutrient loads in the basins is needed for achieving it, taking into consideration expected climate change for the region?
- How can we better assess the impacts of human pressure on aquatic ecosystems and deal with the uncertainty related to its impacts?
- Is this needed nutrient reduction technically feasible and economically sustainable?
- What are consequences of ecosystem deterioration on the socio-economy of the area? How human activities are affected by environmental quality?
- To which extent are you willing to change your life style (diet, habits,...) to improve water quality in the river and marine ecosystems ?
- How to better integrate public participation into decision ?
- How communication among parts can support decision strategies?

#### 5 LITERATURE

- Billen G., Garnier J. & Hanset Ph. (1994). Modelling phytoplankton development in whole drainage networks: the RIVERSTRAHLER model applied to the Seine river system. *Hydrobiologia*, 289:119-137.
- Billen G. & Garnier J. (1999). Nitrogen transfers through the Seine drainage network: a budget based on the application of the Riverstrahler model. *Hydrobiologia*, 410: 139-150.
- Billen, G., Garnier, J. (2007). River basin nutrient delivery to the coastal sea: assessing its potential to sustain new production of non siliceous algae. *Mar. Chem*, 106: 148-160. doi: 10.1016/j.marchem.2006.12.017
- Cadee and Hegeman, 1991 Cadee, G.C. & J. Hegeman. 1991. Phytoplankton primary production, chlorophyll and species composition, organic carbon and turbidity in the Marsdiep in 1990, compared with foregoing years. *Hydrobiol. Bull.* 25: 29-35.
- Garnier J., Billen G. & Coste M. (1995). Seasonnal succession of diatoms and Chlorophyceae in the drainage network of the river Seine: Observations and modelling. *Limnol. Oceanogr.* 40: 750-765.
- Garnier J., d'Ayguessives A., Billen G., Conley D. & Sferratore A. (2002d). Silica dynamics in the hydrographic network of the Seine River. *Oceanis*, 28 : 487-508
- Garnier J., Billen G., Hannon E., Fonbonne S., Videnina Y. & Soulie M. (2002a)- Modeling transfer and retention of nutrients in the drainage network of the Danube River. *Estuar. Coast. Shelf Sci.*, 54: 285-308.
- Lancelot, C, Spitz, Y, Gypens, N, Ruddick, K, Becquevort, S, Rousseau, V, Lacroix, G, Billen, G. 2005. Modelling diatom-Phaeocystis blooms and nutrient cycles in the Southern Bight of the North Sea: the MIRO model. *Marine Ecology Progress Series*. 289: 63-78.

- Lancelot C., Gypens N., Billen G., Garnier J. and Roubéix V. 2007. Testing an integrated river–ocean mathematical tool for linking marine eutrophication to land use: The Phaeocystis-dominated Belgian coastal zone (Southern North Sea) over the past 50 years. *J. Mar. Syst.* 64(14): 216-228.
- Lancelot C., Rousseau, V. and N. Gypens. Ecologically-based reference for Phaeocystis colonies in eutrophied Belgian coastal waters (Southern North Sea) based on field observations and ecological modeling. *Journal of Sea Research* (61: 44–49 ).
- Lancelot C., Thieu V., Polard A., Gypens N., Billen G., Garnier, J. and W. Hecq. Ecological and economic effectiveness of nutrient reduction policies on coastal Phaeocystis colony blooms in the Southern North Sea: an integrated modeling approach
- Thieu V., Billen G., Garnier J. (2009). Nutrient transfer in three contrasting NW European watersheds: the Seine, Somme, and Scheldt Rivers. A comparative application of the Seneque/Riverstrahler model, *Water Research*, 43(6):1740-1754
- Thieu V., J.Garnier, G. Billen (in press). Assessing impact of nutrients mitigation measure along rivers continuum to southern bight of the North Sea, article submitted to *Science of the Total Environment*